UBVRI photometry of Southern Sky BL Lacs

R. R. Sefako[1], O. C. de Jager[1] and H. Winkler[2]

[1] *Space Research Unit, Potchefstroom University, Potchefstroom, 2520, South Africa*
[2] *Dept of Physics, Soweto Campus, Vista University, Johannesburg, South Africa*

Abstract. Seventeen southern sky BL Lacs were observed in UBVRI using the CCD Camera on the 1.0m telescope at the South African Astronomical Observatory (SAAO) in Aug and Nov 1999. The analyses of all the seventeen sources are now complete, and are available via anonymous ftp (ftp pukrs1.puk.ac.za/pub/Blazars). A few examples of our results are however given in this paper. Whereas PKS 2005-489 and 2155-304 appear to have been in a high state, PKS 0048-097 and PKS 0521-365 showed evidence of variability on a time-scale of a few days, with the amplitude of variability increasing towards short wavelengths. This is consistent with observations of gamma-ray BL Lacs, which show similar behaviour in optical and X-rays.

I INTRODUCTION

BL Lacs are the only members of the population of extragalactic sources which have been observed at TeV energies. They emit their energy over a broad range of the spectrum (radio to γ-rays), with signatures of variability in optical, X-rays and γ-rays, which are large compared to other AGNs. BL Lacs are highly polarized non-thermal sources with compact flat-spectrum radio cores. Most BL Lacs were identified in radio and X-ray surveys. Whereas those identified in X-rays (XBLs) are mostly nearby, the radio selected BL Lacs (RBLs) have a larger distance scale. Whereas a few XBLs were detected as TeV sources, we find that the RBLs were mostly detected as EGRET sources (see e.g. Lin et al. 1997, 1999).

The number of BL Lacs known presently are mostly northern sources, which constitute $\sim$75% of all known BL Lacs. Convincing detections of VHE photons from BL Lacs have mainly been made from Northern Hemisphere sources, which include Mrk 421 (Punch et al. 1992), Mrk 501 (Quinn et al. 1996) and 1ES 2344+514 (Catanese et al. 1998). TeV observations of Southern Sky sources mostly gave upper limits (e.g. Roberts et al. 1999). Besides PKS 2155-304, which has also been recently confirmed as a TeV source (Chadwick et al.

1999), none of the southern BL Lacs have been well monitored. Therefore, it is justifiable to claim that there are a number of BL Lacs that have not been identified from the southern skies, and probably with advances in VHE ground-based telescopes, some are likely to be identified as TeV sources in future. Our objective is to monitor Southern Sky BL Lacs in optical, and such information can be combined with contemporary X-ray observations for modeling purposes to identify further TeV candidates.

II OBSERVATIONS

CCD observations in the UBVRI of several Southern BL Lacs were carried out with the SAAO 1.0m telescope in Sutherland during Aug and Nov 1999. A number of E-regions standard stars were also observed for comparison and determination of apparent magnitudes of the target sources. The data were cleaned and flat-fielded using the IRAF image-processing software at SAAO in Cape Town. Table 1 gives a list of BL Lacs that were observed.

The data were analysed and the differential photometry of all seventeen sources have been obtained. We used the E-region stars and, in some cases, apparently non-variable stars which appear on the frame of the target source as standard stars. If the stars on the frame do not have known published magnitudes, we used the E-regions stars to determine their magnitudes which were eventually used to determine the differential photometry (as shown in Table 2). Atmospheric extinction and Galactic reddening corrections were not taken into account in our analysis, since the 'standard' stars were mostly on the same frame as the target. The results of the rest of the observations will be released in the near future.

III RESULTS

The UBVRI magnitudes of six BL Lacs are listed in Table 2 together with the catalogued V values of Padovani & Giommi (1995). Variability is evident for some of these sources. PKS 2005-489 seemed to be in a high state, with its V-band flux about four times larger during Aug/Sep 1999 (in comparison to its catalogued value), whereas the V-band flux from PKS 2155-304 increased by 80% during Sep 1999. Even though PKS 0048-097 and PKS 0521-365 were close to their respective low states, they show evidence of variability on a time-scale of a few days (see Figure 1). We noted however that $\Delta B > \Delta I$ for both PKS 0048-097 and PKS 0521-365, which means the amplitude of variability increases towards higher frequencies.

In Fig. 2, we show the spectra of PKS 2005-489 and PKS 2155-304, with our UBVRI points included. The other data points (Infrared) for both sources are from the Catalog of Infrared Observations (NASA RF–1294, 3rd Edition).

TABLE 1. A list of BL Lacs that were observed in Aug and Nov 1999.

Object	z	Time when observed	Filters	Frames
PKS 2005-489	0.071	24 Aug - 5 Sep	UBVRI	42
MH 2136-428		26 Aug - 5 Sep	BVRI	20
PKS 2155-304	0.117	24 Aug - 5 Sep	UBVRI	40
PKS 2254-204		24 Aug - 27 Aug	BVRI	10
MS 2306-223	0.137	25 Aug, 24 - 29 Nov	BVRI	21
PKS 2316-423	0.055	25 Aug - 5 Sep, 26 - 29 Nov	BVRI	36
PKS 0048-097	> 0.2	25 Aug - 5 Sep, 28, 29 Nov	BVRI	32
PKS 0215+015	1.715	25 Aug - 5 Sep, 27, 28 Nov	BVRI	28
PKS 0301-243		24 Aug - 5 Sep, 25 - 29 Nov	BVRI	36
PKS 0338-214		24 Aug - 5 Sep, 25 - 29 Nov	BVRI	40
EXO 0423-084	0.039	24 Aug - 5 Sep, 27 - 29 Nov	BVRI	36
PKS 0521-365	0.055	27 Aug - 5 Sep, 24 - 29 Nov	BVRI	40
PKS 0537-441	0.896	01 Sep - 4 Sep, 24 - 29 Nov	BVRI	28
PKS 0548-322	0.069	30 Aug - 2 Sep, 27 Nov	BVRI	16
PKS 0219-164	0.698	25 Nov - 29 Nov	BVRI	12
RXJ 0316-260		25 Nov - 29 N0v	BVRI	12
EXO 0556-383		27 Nov	BVRI	4

TABLE 2. Sample results of our data for the 2nd of Sep. 1999. V^p represents visual magnitudes published in Padovani & Giommi (1995). Errors are estimated to be ~ 0.05 mag.

Object	MJD	U	B	V	V^p	R	I
PKS 2005-489	51423.978	12.55	13.11	12.80	14.4	12.41	12.00
PKS 2155-304	51423.993	12.52	13.12	12.84	13.5	12.54	12.13
PKS 2316-423	51424.019		16.57	15.46	14.5	14.84	14.14
PKS 0048-097	51424.040		16.9	16.45	16.3	16.06	15.50
EXO 0423-084	51424.086		17.29	15.98	15.9	15.23	14.42
PKS 0521-365	51424.103		15.61	14.92	14.6	14.38	13.74

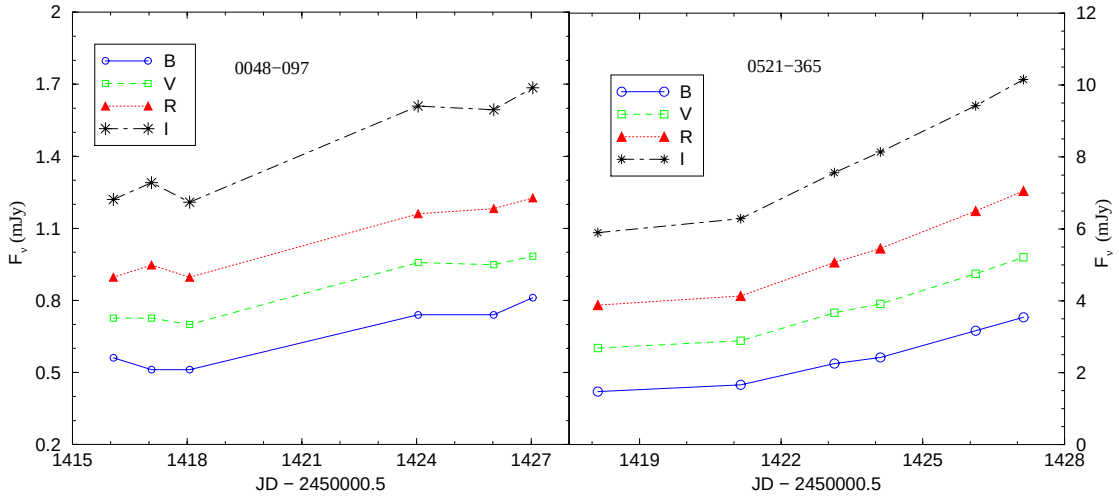

FIGURE 1. BVRI light-curves of PKS 0048-097 and PKS 0521-365. Vertical axes' labels are for PKS 0048-097 (left) and PKS 0521-365 (right).Errors are less than ∼0.06 mJy.

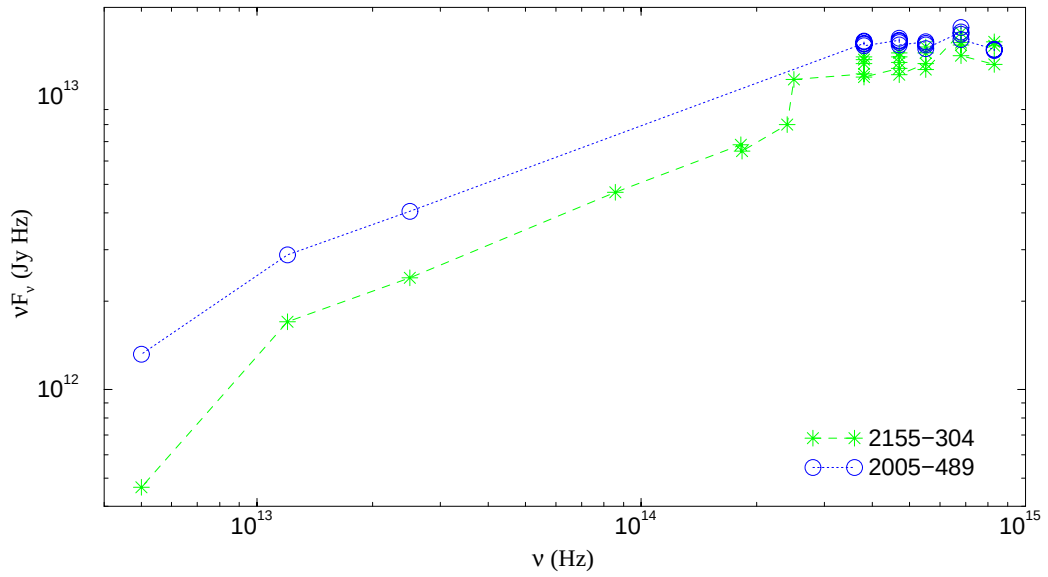

FIGURE 2. SED of PKS 2005-489 and PKS 2155-304 from far the IR (60 μm) to the visual band (0.36μm). Optical data are from our analysed data.

IV CONCLUSIONS

Whereas BL Lac variability is a common feature, our visual multicolor observations provide important information concerning the relative flux change vs. frequency. The observation of an increasing amplitude of flux variability towards higher frequencies (in this case for PKS 0048-097 and PKS 0521-365) should be combined with simultaneous X-ray observations. This synchrotron feature in the optical/X-ray region of the spectrum should also imply a similar behaviour in the inverse Compton (γ-ray) component of the spectrum.

REFERENCES

Catanese, M., et al., 1998, ApJ, 501, 616
Chadwick, P. M., et al., 1999, ApJ, 513, 161
Lin, Y. C., et al., 1999, ApJ, 525, 191
Lin, Y. C., et al., 1997, ApJ, 476, L11
Padovani, P., Giommi, P., 1995, MNRAS, 277, 1477
Punch, M., et al., 1992, Nature, 160, 477
Quinn, J., et al., 1996, ApJ, 456, L83
Roberts, M., et al., 1999, ASP Conference Series on *BL Lac Phenomenon*, Turku, Finland, ed. L. O. Takalo & A. Sillanpää, Vol. 159, 233